Performance Analysis of Rayleigh Fading Channels in MIMO-OFDM Systems using BPSK and QPSK Modulation Schemes

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Abstract—Multiple Input Multiple Output (MIMO) systems are wireless systems with multiple antenna elements at both ends of the link. MIMO systems have the ability to exploit, rather than combat, multipath propagation and promise a significant increase in capacity. MIMO communications use multiple antennas at both the transmitter and receiver to exploit the spatial domain for spatial multiplexing and/or spatial diversity. In contrast to spatial multiplexing the purpose of spatial diversity is to increase the diversity order of a MIMO link to mitigate fading by coding a signal across space and time, so that a receiver could receive the replicas of the signal and combine those received signals constructively to achieve a diversity gain. MIMO and OFDM are commonly thought to be the key techniques for next-generation wireless LAN and 4G mobile communications. In this paper we analyze the Bit Error Rate (BER) of Rayleigh Fading Channels in MIMO-OFDM systems using BPSK and QPSK Modulation Schemes.

Keywords—BER, BPSK, Diversity, Fading, MIMO, Modulation, QPSK

Abbreviations—Bit Error Rate (BER), Binary Phase Shift Keying (BPSK), Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Quadrature Phase Shift Keying (QPSK)

I. INTRODUCTION

OFDM, which is also popularly known as simultaneous MFSK, has been widely implemented in high-speed digital communications in delay-dispersive environments. Basically it is a Multi-Carrier Modulation (MCM) technique. OFDM was first proposed by Chang, (1966). Chang proposed the principle of transmitting messages simultaneously over multiple carriers in a linear band-limited channel without ISI and ICI. The initial version of OFDM employed a large number of oscillators and coherent demodulators. In 1971, DFT was applied to the modulation and demodulation process by Weinstein and Ebert, (1971). In the year 1980, Peled & Ruiz introduced the notion of cyclic prefix to maintain frequency orthogonality over the dispersive channel [Andrews et al., 2007]. It is commonly deemed that OFDM is a major technique for beyond-3G wireless multimedia communications.

In OFDM technology, the multiple carriers are called subcarriers, and the frequency band occupied by the signal carried by a subcarrier is called a sub-band. OFDM achieves orthogonality in both the time and frequency domains. The most attractive feature of OFDM is its robustness against multipath fading, but with a low complexity; that is, it can reliably transmit data over time-dispersive or frequency selective channels without the need of a complex time-domain channel equalizer. OFDM can be efficiently implemented using FFT.

Other advantage of OFDM is that it achieves robustness against narrowband interference, since narrowband interference only affects a small fraction of the subcarriers. In OFDM, frequency diversity can be exploited by coding and interleaving across subcarriers in the frequency domain [Al-Akaidi & Daoud, 2006]. Here even different modulation formats and data rates can be implemented on different subcarriers depending on the channel quality of individual sub-bands. OFDM enables bandwidth-on-demand technology and higher spectral efficiency and contiguous bandwidth for operation is not required [Mitalee Agrawal & Yudhishthir Raut, 2011].

However, the high PAPR of the OFDM signal places a strict requirement on power amplifiers [Peled & Ruiz, 1980].

For this reason, 3GPP LTE employs SC-FDMA for transmission to reduce the strict requirement on power amplifiers in MSs. Also, multicarrier systems are inherently more susceptible to frequency offset and phase noise; thus, frequency jitter and Doppler shift between the transmitter and receiver cause Inter-Carrier Interference (ICI), which becomes a challenge in case of medium or high mobility.

OFDM splits the bit stream into multiple parallel bit streams of reduced bit rate, modulates them using a Mary modulation, and then transmits each of them on a separate subcarrier. The amplitude spectrum of each modulated subcarrier using PSK or QAM has a sinc shape. At the peak spectrum response of each subcarrier, the spectral responses of all other subcarriers are identically zero [Armada, 2001]. This improves the spectral efficiency. The use of narrow band flat-fading sub channels can effectively resist frequency selective fading. Each modulated subcarrier in the OFDM signal can be an MPSK, MASK, or MQAM signal. Thus, the OFDM signal can be obtained first by 1: N serial-to-parallel (s/p) conversion and then by converting each of the N streams to one of the N subcarriers [Bahai et al., 2002]. Their sum is then unconverted to the RF band. For each subcarrier, there is a complete modulator, which typically consists of a subcarrier oscillator, one (for MASK) or two (for MQAM and MPSK) multipliers, and an adder. A phase shifter is also required for MQAM and MPSK. For pass band modulation, a mixer and a band pass filter are required for up conversion.

The receiver consists of a down convertor to translate the signal to the baseband. The baseband OFDM signal is then demodulated by a bank of N demodulators at N subcarrier frequencies, one for each of the subcarriers. The subcarrier demodulator can be a standard MPSK, MASK, or MQAM demodulator, which consist of oscillators, multipliers, integrators, and threshold detectors [Hermann Rohling, 2011].

A frequency-selective MIMO channel has to use a maximum likelihood or a suboptimal equalization, which has a complexity that grows exponentially with the product of the bandwidth and the delay spread. OFDM modulation can transform a frequency-selective fading channel of bandwidth B into N orthogonal flat fading channels, which can be efficiently calculated using IFFT [Yong Soo Cho et al., 2010]. MIMO-OFDM is based on the same idea; it converts a frequency-selective MIMO channel into multiple flat fading channels using the OFDM technique [Armstrong, 2002]. MIMO-OFDM is preferred over MIMO-SC in recent wireless communication standards, such as HSPA+, 3GPP LTE, 3GPP2 UMB, IEEE 802.16e/m, and IEEE 802.11n [Fullmer & Garcia-Luna-Aceves, 1995].

As in MC-CDMA, where CDMA is overlaid on OFDM, MIMO can also easily be overlaid on OFDM for diversity transmission or spatial multiplexing. Unlike the single antenna OFDM case, the MIMO delay-spread channel, in general, provides both a higher diversity gain and a higher multiplexing gain than the MIMO flat fading channel does. The bit stream is first demultiplexed into a few sub streams. Each of the sub streams is then further OFDM-modulated and transmitted from an antenna. This procedure is reversed at the receiver. The resulting MIMO-OFDM receiver must perform time synchronisation; frequency offset estimation and correction, and parameter estimation, by using a preamble consisting of one or more training sequences.

MIMO-OFDM can be implemented as space-time coded OFDM (ST-OFDM), space-frequency coded OFDM (SF-OFDM), and space-time-frequency coded OFDM (STF-OFDM). ST-OFDM enables only a space diversity of N_tN_r, while SF-OFDM and STF-OFDM can usually achieve the maximum diversity order of $(L+1)N_tN_r$, L being the number of multipaths [Bahai et al., 2002]. For the reason, the SF-OFDM is the most popular coding technique in MIMO-OFDM. Also for SF-OFDM, the maximum achievable diversity is derived as $G_d=\min((L+1)\ N_tN_r,\ NN_r) = (L+1)\ N_tN_r$, where N is the number of OFDM subcarriers and typically $N> (L+1)\ N_t$.

II. REVIEW ON MIMO

MIMO systems are wireless systems with multiple antenna elements at both ends of the link. MIMO systems can be used for beam forming, diversity combining, or spatial multiplexing. The first two applications are the same as for the smart antennas, while spatial multiplexing is the transmission of multiple data streams on multiple antennas in parallel, leading to a substantial increase in capacity [Bauml et a., 1996]. MIMO technology and turbo coding are the two most prominent recent breakthroughs in wireless communication. MIMO technology promises a significant increase in capacity.

MIMO systems have the ability to exploit, rather than combat, multipath propagation. The separability of the MIMO channel relies on the presence of rich multipath, which makes the channel spatially selective. Thus, MIMO effectively exploits multipath [3GPP, 2001]. In contrast, some smart antenna systems perform better in the LOS case, and their optimization criteria are based on the DoA/DoD. Although some smart antenna systems generate good results in the non-LOS channel, they mitigate multipath rather than exploit it.

The maximum spatial diversity obtained for a non-frequency selective fading MIMO channel is proportional to the product of the number of receive and transmit antennas [Bharghavan et al., 1994]. In the uncorrelated Rayleigh fading channel, the MIMO channel capacity/throughput limit grows linearly with the number of transmit or receive antennas, whichever is smaller. According to the analysis and simulation performance schemes, MIMO can provide a spectral efficiency as high as 20-40 bit/s/Hz [3GPP, 2004]. MIMO and OFDM are commonly thought to be the key techniques for next-generation wireless LAN and 4G mobile communications. MIMO-OFDM is used in IEEE 802.11n, IEEE 802.16m, and LTE.

Like the single-antenna case, channel estimation for MIMO can be implemented based on training sequences or by using a blind technique. In the MIMO system, there are

more channel parameters to be estimated. It is desirable to keep the training sequences from the multiple transmit antennas mutually orthogonal in some form (time, frequency, or code) to enhance estimation accuracy [Boithias, 1987]. The training sequences should typically have good auto and cross-correlation properties.

There are many transmission schemes over MISO or MIMO channels in the literature. These schemes rely on certain CSI available at the transmitter and/or receiver side. CSI at the receiver can be easily estimated using a training-based or blind technique. CSI at the transmitter can be obtained by feedback of the receiver's channel estimation based on the downlink training data (e.g., in TDD mode), or from the use of training or pilot data in the uplink (e.g., in FDD mode). Feedback usually causes some delay and this delay should be insignificant compared to the coherent time. In a fast changing channel, frequent channel estimation and feedback is required; in order to reduce the overhead on the reverse link, the slowly changing statistics or partial information of the channel can be fed back over the channel [Boutin et al., 2008]. When full CSI is available at the transmitter, the transmitter can employ the Eigen vector steering technique to approach the full capacity of the MIMO channel. The availability of the CSI at the receiver is assumed by most multi-user MIMO methods.

Coherent space-time decoding always requires knowledge of the MIMO channel as well as timing and frequency synchronization at the receiver. A timing offset introduces a pure delay convolutional channel; thus, timing synchronization can be lumped into channel estimation [3GPP, 2003]. Frequency synchronization requires separate implementation. Preamble- based channel estimation is the most fundamental channel estimation method. A number of training or pilot symbols that are known to both the transmitter and the receiver are placed at the start of a frame. These symbols are known as the preamble. The decision-directed channel estimation method begins with channel estimation using the preamble [Zhengdao Wang, 1998]. Using the estimated channel, symbols are then decoded for a block within the coherent interval of the channel. These decoded symbols are used as the training symbols, and refined channel estimation is obtained. The decision-directed method is valid for slowly varying channels, at least for high SNR. The semi blind channel estimation approach can improve spectrum efficiency by exploiting the signal properties as well as the preamble.

III. RAYLEIGH FADING CHANNEL

Rayleigh fading is a statistical model for the strong influence of a propagation environment on a radio signal, used by wireless communication devices [Anderson & Salz, 1965]. Rayleigh fading models consider that the magnitude of a signal that has passed through a transmission channel or medium will vary often and in a random manner, or fade, according to a Rayleigh distribution- the radial component of the addition of two uncorrelated Gaussian random variables. For wireless communications, the envelope of the received carrier signal is Rayleigh distributed; such a type of fading is called Rayleigh fading [Arnold & Bodtmann, 1984]. This can be caused by multipath with or without the Doppler Effect.

Rayleigh fading is observed as a sensible model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban ambience on radio signals. Rayleigh fading is most applied in situations when there is less or no dominant propagation along a line of sight between the transmitter and receiver. Presence of a dominant line of sight indicates that Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it finally reaches the receiver. According to the central limit theorem, if there is sufficiently too much scattering, the impulse response of the channel can be modelled well as a Gaussian process, not bothering about the distribution of the individual components [Aulin & Sundberg, 1981]. Absence of a dominant component to scatter clearly indicates that the process will have zero mean and phase evenly distributed between 0 and 2π radians. The envelope of the channel response will therefore be known as a Rayleigh distributed one.

Calling this random variable R, it will have a probability density function

$$P_R(r) = \frac{2r}{\Omega} e^{-r^2/\Omega}, r \geq 0 \text{ where } \Omega = (R^2)$$

In the multipath case, when the dominant signal becomes weaker, such as in the non LOS case, the received signal is the sum of many components that are reflected from the surroundings. These independent scattered signal components that are reflected from the surroundings have different amplitudes and phases (time delays); then the in phase and quadrature components of the received signal can be assumed to be independent zero-mean Gaussian processes. This is derived from the central limit theorem, which states that the sum of a sufficient number of random variables approaches very closely to a normal distribution. When the mobile station moves, the frequency shift of each reflected signal component that arises from the Doppler Effect also has an influence on the fading. Very often, the gain and phase elements of a channel's distortion are represented as a complex number for mathematical convenience. In this scenario, Rayleigh fading is shown by the assumption that the real and imaginary parts of the channel response are well modelled by independent and identically distributed zero-mean Gaussian process so that the amplitude of the response is the sum of two such processes. The absolute requirement is that there may be many scatterers present which indicates that Rayleigh fading can be an optimum and very useful model in heavily built-up city centres, where there is no line of sight between the transmitter and receiver and many buildings and other objects that attenuate, reflect, refract, and diffract the signal [Karn, 1990]. Design engineers whose experimental work when carried out in Manhattan has found near-Rayleigh fading there. In tropospheric and ionospheric signal propagation regions, many particles in the layers of the atmosphere act as scatterers and this kind of disturbed

environment may also approximate Rayleigh fading. If the environment is such that, in addition to the effects of scattering, prevalence of a strongly dominant signal is seen at the receiver means, then such a situation may be better modelled as Rician fading [3GPP, 2003]. One must always remember that the Rayleigh fading channel is a small-scale effect. There will be certain properties of the environment such as path loss and shadowing upon which the fading may be superimposed. The rapidity of the channel fading will be affected by how fast the receiver and/or transmitter are in mobility. Constant motion causes Doppler shift in the received signal components.

IV. BPSK and QPSK Modulation Schemes

Phase shift keying technique is a process that conveys information or data by modulating the phase of a reference signal which is also called as the carrier wave. The function of the demodulator is to determine the phase of the received signal and maps it back to the symbol it represents [Fullmer & Garcia-Luna-Aceves, 1995]. Comparing the phase of the received signal to a reference signal is done by the receiver; hence this system is termed as a coherent one. PSK has an envelope which is constant, and thus the requirements of the transmitter power amplifier are made simple. The bandwidth efficiency of PSK is much more than FSK and more power efficient than ASK and FSK. In BPSK, the carrier signal has constant amplitude but its phase is switched between two values, which are separated by π, to represent 0 and 1, respectively [Tobagi & Kleinrock, 1975]. BPSK (also sometimes called PRK, Phase Reversal Keying, or 2PSK) is the simplest form of phase shift keying (PSK). Two phases are made use here which are separated by 180 degrees and so can also be termed as 2-PSK. It does not particularly matter exactly where the constellation points are positioned in a figure, since it is always shown on the real axis, at 0 degrees and 180 degrees. This modulation technique is the most robust and efficient of all the PSKs since it takes the highest peak of noise or distortion to make the demodulator reach an incorrect decision. In the presence of an arbitrary phase-shift introduced by the communications channel, the demodulator reaches an incorrect decision. For high data rate applications it is mostly unsuitable since it can modulate at 1 bit/symbol [Deng & Hass, 1997]. In the presence of an arbitrary phase-shift introduced by the communications channel, the demodulator is unable to tell which constellation point is which. As a result, the data is often differentially encoded prior to modulation. BPSK is functionally equivalent to 2-QAM modulation.

QPSK is also known as quaternary PSK, quadriphase PSK, 4-PSK, or 4-QAM. QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK helps to encode two bits per symbol, with gray coding so that the bit error rate (BER) can be minimized-sometimes it is misperceived as twice the BER of BPSK [Frederiksen & Prasad, 2002]. The mathematical analysis shows that QPSK can be used either for doubling the data rate compared with a standard BPSK system while maintaining the same bandwidth of the signal, or to maintain the data rate of BPSK but halving the requirement of bandwidth needed. In the latter case, the BER of QPSK is exactly the same as the BER of BPSK and deciding differently is a common chaos when QPSK is considered or described. When agencies such as the Federal Communication Commission allocates a radio communication channel giving a prescribed bandwidth, only then the advantage of QPSK over BPSK becomes very clear and evident: QPSK transmits twice the data range in a given bandwidth when compared to BPSK at the same BER [John & Binghan, 1990]. The greatest penalty that is paid here is that QPSK transmitters and receivers are very much complicated than the ones for BPSK. However, with recent technologies concerned to electronics, the penalty in cost is somewhat moderate. Differentially encoded QPSK is often used in practise at the receiving end since phase ambiguity problems are of great concern if we opt for BPSK schemes [Burns, 2003].

V. Results and Discussions

In this paper one of the important topic in wireless communications, which is the concept of Rayleigh fading is demonstrated by the approach available in MATLAB. In this section, the results obtained from the MATLAB simulations are discussed. It is necessary to explore what happens to the signal as it travels from the transmitter to the receiver. Then it is very easy to understand the concepts in wireless communications. As explained earlier, one of the important aspects of the path between the transmitter and receiver is the occurrence of fading. MATLAB provides a simple and easy way to demonstrate fading taking place in wireless systems. The radio frequency signals with appropriate statistical properties can readily be simulated. Statistical testing can subsequently be used to establish the validity of the fading models frequently used in wireless systems. The BER performance of MIMO OFDM systems in Rayleigh fading channels has been analysed with two basic different modulation schemes (BPSK and QPSK). After comparing the simulation result obtained by plotting the Bit Error Rate against the Signal to Noise Ratio (SNR), we get the following two results.

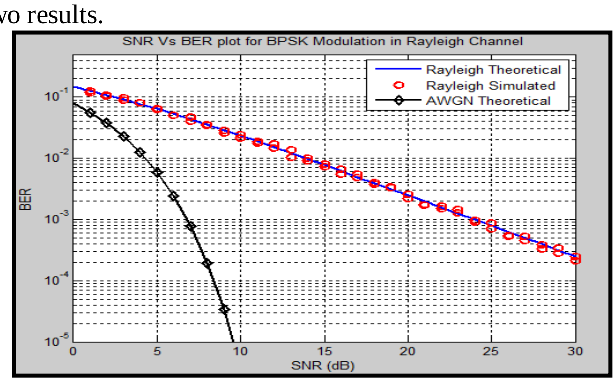

Figure 1 – SNR Vs BER Plot for BPSK Modulation in Rayleigh Fading Channel

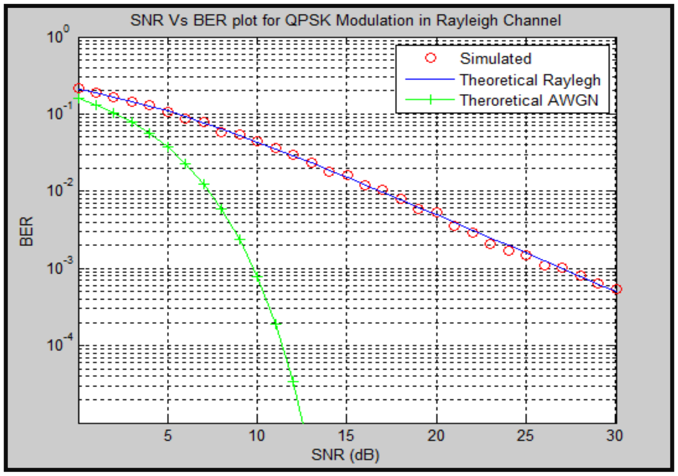

Figure 2 – SNR Vs BER Plot for QPSK Modulation in Rayleigh Fading Channel

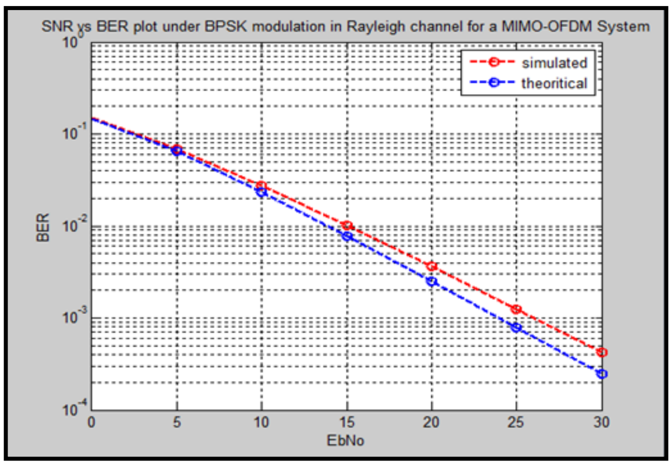

Figure 3 – SNR Vs BER Plot under BPSK Modulation in a Rayleigh Fading Channel for a MIMO-OFDM System

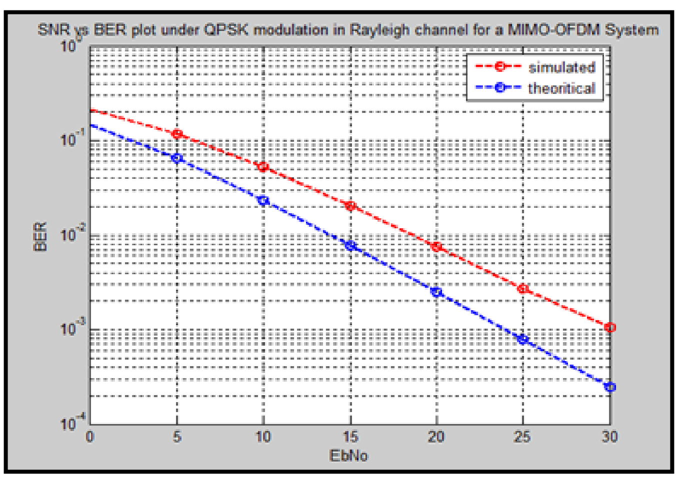

Figure 4 – SNR Vs BER Plot under QPSK Modulation in a Rayleigh Fading Channel for a MIMO-OFDM System

VI. Conclusions

When the Signal to Noise Ratio versus Bit Error Rate was evaluated under BPSK and QPSK modulation schemes for Rayleigh fading channels in a general communication system, the graphs are obtained as shown in Figure 1 and Figure 2. On the careful examination of Figure 1 and Figure 2 we can find that the number of errors in the BPSK modulation scheme is less when compared to the number of errors in the QPSK modulation scheme. Thus the performance analysis of Rayleigh Fading Channels in a general communication system under BPSK modulation scheme is found to be more efficient. Similarly when the Signal to Noise Ratio versus Bit Error Rate was evaluated under BPSK and QPSK modulation schemes for Rayleigh fading channels in a MIMO-OFDM system, the graphs are obtained as shown in Figure 3 and Figure 4. If we analyse graphs 3 and 4 respectively, we can again observe that the number of errors in BPSK modulation scheme is comparatively less to that of the QPSK modulation scheme. So it is obvious that BPSK modulation serves good for Rayleigh fading channels in MIMO-OFDM systems. Future works can be carried out by enhancing the performance of any general communication system or a MIMO-OFDM system by changing the modulation scheme respectively.

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